AMENDMENTS TO THE CLAIMS

The following listing of claims will replace all prior versions and listings of claims in the application.

LISTING OF CLAIMS

1. (Currently Amended) An off-line feed rate scheduling method of a CNC machining process that is performed according to workpiece geometry and a given set of NC code provided from a CAD/CAM system, the method comprising:

selecting a constraint variable and inputting a reference value related to the constraint variable;

estimating a cutting configuration where a maximum constraint variable value (CVV) occurs through ME Z-map modeling;

obtaining the estimated cutting configuration and estimating a specific rotation angle (φ_s) where the maximum constraint variable value occurs through constraint variable modeling;

calculating a feed rate that satisfies the reference value related to the constraint variable at the estimated specific rotation angle; and

applying the calculated feed rate to the NC code,

wherein the calculating a feed rate comprises:

inputting specific feed rates f_1 and f_2 ($f_1 < f_2$);

calculating maximum constraint variable values CVV_1 and CVV_2 corresponding to the feed rates f_1 and f_2, respectively, at the specific rotation angle;

approximating a feed rate f_{next} that corresponds to a reference value RV of a constraint variable value using the formula,

$$f_{next} = f_1 + \frac{(RV - CVV_1)(f_2 - f_1)}{CVV_2 - CVV_1};$$

calculating a constraint variable CVV_{next} in the case where the feed rate is f_{next}; and

determining using the formula below if the constraint variable value CVV_{next} when compared to the reference value RV is less than an error limit, applying the feed rate

f_{next} to the NC code when it is less than the error limit, replacing the feed rate f_2 by f_{next} and repeating the process of obtaining f_{next} when this value is not less than the error limit and the reference value RV is greater than the constraint variable value CVV_{next}, and replacing the feed rate f_1 by f_{next} and repeating the process of obtaining f_{next} when this value is not less than the error limit and the reference value is not greater than the constraint variable value CVV_{next},

where

$$\frac{CVV_{next} - RV}{RV} < \text{Error Limit}.$$

2. (Cancelled)

3. (Previously Presented) The method of claim 1, wherein computing cutting configurations through ME Z-map modeling comprises:

searching for node points located in a cutting area;

identifying whether a target node is an edge node or not;

calculating and updating a height value of each node in the cutting area;

moving a target node if it is an edge node and storing movement direction angles;

computing the cutting configurations using the stored angles.

4. (Previously Presented) The method of claim 3, wherein the cutting configurations computed through ME Z-map modeling include at least one of an entry angle, an exit angle, and an axial depth of cut.

5. (Original) The method of claim 3, wherein in the case where a difference between a distance from a tool center to a target node and a tool radius is smaller than a movement limit, this node is designated as an edge node.

6. (Original) The method of claim 1, wherein one of cutting force and machined surface error is selected as a constraint variable.

6 7. (Previously Presented) An off-line feed rate scheduling method for adjusting a cutting force of a CNC machining process that is performed according to workpiece geometry and a given set of NC code instructing paths of a tool provided from a CAD/CAM system, the method comprising:

inputting a reference cutting force;

estimating a cutting configuration where a maximum cutting force occurs through ME Z-map modeling;

receiving the estimated cutting configuration and estimating a specific rotation angle where the maximum cutting force occurs through cutting force modeling;

calculating a feed rate that satisfies the reference cutting force at the estimated specific rotation angle; and

applying the calculated feed rate to the NC code.

8. (Previously Presented) The method of claim 7, wherein the reference cutting force is selected from a reference cutting force RF_1 established to prevent breaking of a tool shank, and a reference cutting force RF_2 established to prevent damage to an edge portion of a tool, RF_1 and RF_2 being calculated by the formulae

$$RF_1 = SF \cdot TRS \cdot S_1$$
$$RF_2 = SF \cdot TRS \cdot S_2$$

where RF_1 represents the reference cutting force considered to avoid breakage of tool shank and RF_2 indicates the reference cutting force to prevent breakage of tool edge; *SF* means safety factor, which is used to make up for unpredictable factors; and TRS means transverse rupture strength of a tool material.

9. (Previously Presented) The method of claim 7, wherein the tool is a flat end milling tool, and cutting force components of each axial direction of three-dimensional Cartesian coordinate according to a rotational angle of the tool are obtained using

$$F_x(j) = \sum_k \sum_i F_x(i,j,k)$$
$$F_y(j) = \sum_k \sum_i F_y(i,j,k)$$
$$F_z(j) = \sum_k \sum_i F_z(i,j,k)$$

where

$$F_x(i,j,k) = [C_1 K_n \cos(\phi - \alpha_r) + K_f K_n C_3 \cos\phi - K_f K_n C_4 \sin(\phi - \alpha_r)] t_c(\phi) B_1$$
$$F_y(i,j,k) = [C_1 K_n \sin(\phi - \alpha_r) + K_f K_n C_3 \sin\phi + K_f K_n C_4 \cos(\phi - \alpha_r)] t_c(\phi) B_1$$
$$F_z(i,j,k) = [-C_2 K_n + K_f K_n C_5] t_c(\phi) B_1$$

and where C_1, C_2, C_3, C_4, and C_5 in the above are calculated by the following:

$$C_1 = \frac{\cos\theta_h}{\sin\theta_{tk}}, \quad C_2 = \frac{\sin\theta_h}{\sin\theta_{tk}} \cdot \cos\alpha_r$$

$$C_3 = \sin\theta_h(\sin\theta_c - \cos\theta_c \cot\theta_{tk})$$

$$C_4 = \frac{\cos\theta_c}{\sin\theta_{tk}}$$

$$C_5 = \cos\theta_h(\sin\theta_c - \cos\theta_c \cot\theta_{tk})$$

and

$$\cos\theta_{th} = \sin\alpha_r \cdot \sin\theta_h,$$

where i is a cutter tooth index, j is an index of a cutter rotation angle, k is an index of a z-axis disk element, φ is an angle position of a cutter edge, α_r is a rake angle, $t_c(\varphi)$ is uncut chip thickness, θ_h is a helix angle, θ_c is a chip flow angle, and K_n, K_f, and B_1 are constants.

10. (Currently Amended) The method of claim 9, wherein K_n, K_f, and θ_c may be obtained by the following formulae,

$$\ln(K_n(i,j,k)) = A_1 - (A_1 - A_2)e^{-(A_3 t_c(i,j,k))^{A_4}}$$

$$K_f(i,j,k) = B_1 - (B_1 - B_2)e^{-(B_3 t_c(i,j,k))^{B_4}}$$

$$\theta_c(i,j,k) = C_1 - (C_1 - C_2)e^{-(C_3 t_c(i,j,k))^{C_4}}$$

where t_c is an actual uncut chip thickness, and A_1, A_2, A_3, A_4, B_1, B_2, B_3, B_4, C_1, C_2, C_3, and C_4 are constants.

11. (Previously Presented) The method of claim 7, wherein the tool is a ball end milling tool, and cutting force components of each axial direction of three-dimensional Cartesian coordinate according to a rotational angle of the tool are obtained using

$$\begin{Bmatrix} F_x \\ F_y \\ F_z \end{Bmatrix} = \begin{bmatrix} A_{11} & A_{12} & A_{13} \\ A_{21} & A_{22} & A_{23} \\ A_{31} & A_{32} & A_{33} \end{bmatrix} \begin{Bmatrix} K_1 \\ K_2 \\ K_3 \end{Bmatrix}$$

where

$$K_1 = K_n$$

$$K_2 = \cos\theta_c K_n K_f$$

$$K_3 = \sin\theta_c K_n K_f$$

$$A_{11} = B_1 \sum_k \sum_i (\cos\alpha_r \cos\phi \cos\theta_h + \sin\alpha_r \sin\phi) \cdot t_c(\phi)$$

$$A_{12} = B_1 \sum_k \sum_i (\sin\alpha_r \frac{1}{f_2} \cos\phi \cos\theta_h - \frac{1}{f_2} \cos\alpha_r \sin\phi - \frac{f_1}{f_2} \cos\alpha_r \cos\phi \sin\theta_h) \cdot t_c(\phi)$$

$$A_{13} = B_1 \sum_k \sum_i (-\frac{f_1}{f_2} \sin\phi + \frac{1}{f_2} \cos\phi \sin\theta_h) \cdot t_c(\phi)$$

$$A_{21} = B_1 \sum_k \sum_i (\cos\alpha_r \sin\phi \cos\theta_h - \sin\alpha_r \cos\phi) \cdot t_c(\phi)$$

$$A_{22} = B_1 \sum_k \sum_i (\sin\alpha_r \frac{1}{f_2} \sin\phi \cos\theta_h + \frac{1}{f_2} \cos\alpha_r \cos\phi - \frac{f_1}{f_2} \cos\alpha_r \sin\phi \sin\theta_h) \cdot t_c(\phi)$$

$$A_{23} = B_1 \sum_k \sum_i (\frac{f_1}{f_2} \cos\phi + \frac{1}{f_2} \sin\phi \sin\theta_h) \cdot t_c(\phi)$$

$$A_{31} = B_1 \sum_k \sum_i (-\sin\theta_h \cos\alpha_r) \cdot t_c(\phi)$$

$$A_{32} = B_1 \sum_k \sum_i (-\sin\alpha_r \frac{1}{f_2} \sin\theta_h - \frac{f_1}{f_2} \cos\alpha_r \cos\theta_h) \cdot t_c(\phi)$$

where i is a cutter tooth index, j is an index of a cutter rotation angle, k is an index of a z-axis disk element, φ is an angle position of a cutter edge, α_r is a rake angle, $t_c(\varphi)$ is uncut chip thickness, θ_h is a helix angle, θ_c is a chip flow angle, and K_n, K_f, B_1, f_1 and f_2 are constants.

12. (Previously Presented) The method of claim 11, wherein K_n, K_f, and θ_c may be obtained by the following formulae:

$$K_n = K_1$$

$$\theta_c = \tan^{-1}(\frac{K_3}{K_2})$$

$$K_f = \frac{K_2}{\cos\theta_c K_n}$$

where K_1, K_2 and K_3 are constants.

13. (Cancelled)

14. (Currently Amended) ~~The method of claim 13,~~ An off-line feed rate scheduling method for adjusting a machined surface error of a CNC machining process that is performed according to workpiece geometry and a given set of NC code instructing paths of a tool provided from a CAD/CAM system, the method comprising:

inputting a reference surface error;

estimating a cutting configuration where a maximum surface error occurs through ME Z-map modeling;

receiving the estimated cutting configuration and estimating a specific rotation angle where the maximum surface error occurs through machined surface error modeling;

calculating a feed rate that satisfies the reference surface error at the estimated specific rotation angle; and

applying the calculated feed rate to the NC code,

wherein the tool is a flat end milling tool, and a cusp error C_h is calculated using the formula

$$C_h = R - \sqrt{R^2 - (\frac{f_t}{2})^2}$$

where R is a tool radius and f_t is an edge feed rate.

15. (Currently Amended) ~~The method of claim 13~~ An off-line feed rate scheduling method for adjusting a machined surface error of a CNC machining process that is performed according to workpiece geometry and a given set of NC code instructing paths of a tool provided from a CAD/CAM system, the method comprising:

inputting a reference surface error;

estimating a cutting configuration where a maximum surface error occurs through ME Z-map modeling;

receiving the estimated cutting configuration and estimating a specific rotation angle where the maximum surface error occurs through machined surface error modeling;

calculating a feed rate that satisfies the reference surface error at the estimated specific rotation angle; and

applying the calculated feed rate to the NC code,

wherein the tool is a ball end milling tool, and a cusp error C_h is calculated using the formula,

$$C_h = R - \sqrt{R^2 - (\frac{D}{2})^2}$$

where $D = \sqrt{(TPD^2 + f_t^2)}$, TPD being an interval between a tool path, R being a tool radius and f_t being an edge feed rate.